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Effect of Gibberellic Acid and Dry Yeast on Growth, Yield, and Essential Oil of Lemon Balm (*Melissa officinalis* L.)

Mahmoud A. Sharaf-Eldin[1*] • Abeer Y. Ibrahim[1] • Hassan M. Korkar[2]

[1] Medicinal and Aromatic Plants Department, National Research Centre, Cairo-12622, Egypt
[2] The Higher Institute of Agricultural Co-Operation, Hadayek Shobra, Cairo-11241, Egypt

Corresponding author: * sharafeldin99@yahoo.com

ABSTRACT

In a field experiment during two successive seasons (2005-2006 and 2006-2007), the effect of gibberellic acid (GA_3) and active dry yeast on growth, yield, and essential oil (EO) of lemon balm plants was investigated. Application of GA_3 and/or active dry yeast increased vegetative characters (i.e. plant height, number of branches, and herb fresh and dry weight per plant) compared to control (sprayed with water only). The maximum mean values of growth characters were obtained as a result of spraying with 6 g l^{-1} yeast + 300 ppm GA_3. The lowest fresh and dry weight of plants were observed with the treatment of 2 g l^{-1} yeast + 0 ppm GA_3 in the first harvest. EO content in the lemon balm herb increased due to the application of GA_3 and/or active dry yeast compared to control. The highest EO yield per plant was observed with the treatment of 6 g l^{-1} yeast + 300 ppm GA_3. The lowest amount of EO yield was obtained with the control treatment. The highest geranial in lemon balm EO occurred with the treatment of 6 g l^{-1} yeast + 300 ppm GA_3.

Keywords: active dry yeast, antioxidant, GA_3, geranial, neral

INTRODUCTION

Lemon balm (*Melissa officinalis* L.; Fam. Lamiaceae) is one of the most important medicinal and aromatic plants due to its culinary properties and grows widely in central and southern Europe and slightly in Asia (Zargari 1990). It is used in conventional medicine for the treatment of headaches, flatulence, indigestion, colic, nausea, nervousness, anemia, vertigo, syncope, malaise, asthma, bronchitis, amenorrhea, cardiac failure, arrhythmias, insomnia, epilepsy, depression, psychosis, hysteria, ulcers and wounds (Zargari 1990; Anon 2002). Recently, several investigators have studied the antioxidative activity of lemon balm (Hohman *et al*. 1999; Triantaphyllou *et al*. 2001; Ivanova *et al*. 2005; Venkutonis *et al*. 2005; Dastmalchi *et al*. 2008). The application of phytohormones, gibberellic acid (GA_3) and/or the unicellular fungi producing auxin, yeast showed different effects on different plants, e.g., GA_3 application on *Tagetes patula* at 100, 200 or 400 ppm increased the plant height, fresh and dry weight per plant, but had no effect on the number of branches (El-Leithy 1987).

The role of gibberellins has been indicated many years ago, Leopold and Kriedeman (1975) emphasized that GA_3 promotes growth by its effect on cell division and cell enlargement. The influence of GA_3 on the plant height was proved through the studies of El-Keltawi (1981) on *Mentha viridis*; Hamza *et al*. (1981) on *Pelargonium ortorum*; El-Leithy (1983) on *Ocimum basilicum*; Salem (1984) on *Chrysanthimum* sp.; and Al-Mulla (1985) on *Tagetes erecta*. Mazhar (1988) reported that GA_3 treatments at 50 and 100 ppm increased the plant height, number of branches, total umbels per plant of *Ammi visnaga* plants. Sharma *et al*. (1988) on *Mentha citrata* indicated that foliar spraying with 100, 200 or 400 ppm of GA_3 increased plant height, number of leaves, fresh and dry weight per plant. Roselle (*Hibiscus sabdariffa*) plants sprayed with dry yeast at a rate of 2 g l^{-1} showed the highest yield of calyxes (Ahmed *et al*. 1998). Khedr and Farid (2000) demonstrated that the effect of dry yeast is due to its effect on induction of endogenous hormones like GA_3 and IAA. Vitamins are known as growth factors influencing physiological process (Chailakhyan 1957). Recently, dry yeast has used as an alternative source to growth substances in bio/organic fertilization system (Khedr and Farid 2000).

The objective of this study was to investigate the growth, yield, and chemical composition of lemon balm plants as influenced by the application of gibberellic acid (GA_3) and/or active dry yeast.

MATERIALS AND METHODS

Seeds of lemon balm (*Melissa officinalis* L.; Fam. Lamiaceae) were supplied by Jelitto GmbH, Germany. Two field experiments were carried out during two successive seasons (2005-2006 and 2006-2007) at the National Research Centre (NRC) Experimental Station (30° 05′ N, 31° 22′ E), Al-Giza Governorate, to study the effect of GA_3 in combination with active dry yeast (*Saccharomyces cerevisiae*) on growth and EO production of lemon balm plants. The main weather information for Cairo, Egypt concerning temperature (T), sunshine (SH) and rainfall (RF) is given in **Table 1**. The physical and chemical analyses of the field experiment soil (**Table 2**) were carried out before planting according to the method of Chapman and Pratt (1978). Ninety kg P_2O_5/ha (calcium superphosphate 15.5% P_2O_5) were applied during ploughing. Plants were side-dressed with 200 kg N/ha (ammonium sulphate 20.5% N) and 65 kg K_2O/ha (potassium sulphate 49% K_2O) in two doses: first dose 30 days after transplanting, second 90 days after transplanting; after first harvest. Furrow irrigation was applied as required. The powder form of the active dry yeast was purchased from the local market. Yeast was activated overnight by sucrose at a rate of 2 g l^{-1} aqueous solution of dry yeast before spraying on the plants. The plants were sprayed drop wet. The GA_3 used was in commercial form of Berelex (gibberellin $C_{19}H_{22}O_6$ contains 90% GA_3) purchased from the local market.

Treatments (T) used in the field experiments were identified as follows: T1 (0 g l^{-1} yeast + 0 ppm GA_3; control sprayed with water), T2 (0 g l^{-1} yeast + 100 ppm GA_3), T3 (0 g l^{-1} yeast + 200 ppm GA_3), T4 (0 g l^{-1} yeast + 300 ppm GA_3), T5 (2 g l^{-1} yeast + 0

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Table 1 Average values of main weather variables in Cairo*.

Feature	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	
T (ºC)	13.5	14.9	17.5	21.0	24.5	27.1	27.7	27.6	25.9	23.4	19.1	15.1	21.4[1]
SH (h)	213	222	243	279	315	372	357	333	309	297	228	201	3369[2]
RF (mm)	5.2	3.5	2.4	1.1	0.6	0.1	0.0	0.0	0.0	1.0	3.4	6.6	23.9[2]

*Source: Meteorological data of Cairo (CLAC, Egypt), average values from 2005 to 2007; SH - sunshine hours; RF – rainfall; [1] – average, [2] – total.

Table 2 Properties of the soil used for growing lemon balm.

Clay (%)	Silt (%)	Sand (%)	$C_{org.}$ (%)	$M_{org.}$[1] (%)	pH	EC (Sm^{-1})	N[2] (ppm)	P[3] (ppm)	K[3] (ppm)
14.94	29.75	55	0.16	0.23	8.23	2.8	480	37.8	35.7

[1] – organic matter, [2] – total, [3] – available.

Table 3 Effect of GA_3 and dry yeast on growth, yield and essential oil percentage of lemon balm during the first season.

Treatments	Gibberellic acid (GA_3 in ppm)	Plant height (cm)		Number of branches		Plant fresh weight (g)		Plant dry weight (g)		Plant dry weight ha^{-1} (t)		Essential oil (% dry weight)	
		I*	II**	I*	II**	I*	II**	I*	II**	I*	II**	I*	II**
Yeast	0	38.21	32.88	5	9	461.78	370.65	122.36	90.40	3.50	2.57	0.37	0.17
0 g l^{-1}	100	48.20	44.10	8	12	520.32	484.20	126.91	122.58	3.62	3.50	0.42	0.21
	200	56.20	52.30	11	14	631.97	523.57	154.14	127.70	4.40	3.64	0.40	0.22
	300	63.11	57.60	12	17	708.94	592.30	172.91	149.95	4.93	4.28	0.49	0.28
Mean value of yeast 0 g l^{-1}		45.62	38.5	9	13	411.48	392.6	112.36	95.76	3.21	2.74	0.47	0.28
Yeast	0	45.62	38.50	9	13	411.48	392.60	112.36	95.76	3.21	2.74	0.47	0.28
2 g l^{-1}	100	52.10	46.10	9	16	548.50	498.64	137.13	126.24	3.93	3.59	0.49	0.27
	200	58.90	53.20	14	16	652.30	613.54	159.10	149.64	4.55	4.28	0.49	0.31
	300	60.40	54.40	14	17	685.09	628.72	159.32	159.17	4.55	4.55	0.50	0.30
Mean value of yeast 2 g l^{-1}		54.26	48.05	11.50	15.50	574.34	533.38	141.98	132.70	4.06	3.79	0.49	0.29
Yeast	0	52.40	47.10	8	14	555.84	520.32	135.57	126.91	3.88	3.62	0.49	0.30
4 g l^{-1}	100	59.30	52.00	10	17	640.00	548.40	156.10	138.84	4.45	3.97	0.51	0.31
	200	65.30	60.10	16	20	718.69	675.33	171.12	164.72	4.88	4.71	0.51	0.31
	300	65.00	62.00	14	19	726.30	723.00	177.15	183.04	5.07	5.24	0.49	0.30
Mean value of yeast 4 g l^{-1}		60.50	55.30	12.00	17.50	660.21	616.76	159.99	153.38	4.57	4.39	0.50	0.31
Yeast	0	59.40	54.60	13	18	632.60	567.30	154.29	138.37	4.40	3.95	0.51	0.32
6 g l^{-1}	100	62.10	57.30	11	19	699.18	632.10	170.53	160.03	4.88	4.57	0.51	0.32
	200	69.32	64.20	18	22	758.80	718.50	185.07	175.24	5.28	5.00	0.51	0.31
	300	69.12	65.00	16	24	777.00	747.96	189.51	189.36	5.40	5.40	0.51	0.32
Mean value of yeast 6 g l^{-1}		64.99	60.28	14.50	20.75	716.90	666.47	174.85	165.75	4.99	4.73	0.51	0.32
Mean value of GA_3 at: 0		48.91	43.27	8.75	13.50	515.43	462.72	131.15	112.86	3.75	3.22	0.46	0.27
100		55.43	49.88	9.50	16.00	602.00	540.84	147.67	136.92	4.22	3.91	0.48	0.28
200		62.43	57.45	14.75	18.00	690.44	632.74	167.36	154.33	4.78	4.41	0.48	0.29
300		64.41	59.75	14.00	19.25	724.33	673.00	174.72	170.38	4.99	4.87	0.50	0.30
LSD (5%)	GA_3	1.82	1.72	1.2	1.0	13.6	14.5	7.4	8.5	0.33	0.31	0.05	0.04
	Yeast	2.45	2.14	0.8	0.85	12.2	10.67	6.8	9.3	0.19	0.14	0.03	0.02
	GA_3 x Yeast	3.1	2.94	1.3	1.1	22.3	24.58	12.6	14.1	0.45	0.33	0.085	0.06

*I – first harvest, **II – second harvest.

ppm GA_3), T6 (2 g l^{-1} yeast + 100 ppm GA_3), T7 (2 g l^{-1} yeast + 200 ppm GA_3), T8 (2 g l^{-1} yeast + 300 ppm GA_3), T9 (4 g l^{-1} yeast + 0 ppm GA_3), T10 (4 g l^{-1} yeast + 100 ppm GA_3), T11 (4 g l^{-1} yeast + 200 ppm GA_3), T12 (4 g l^{-1} yeast + 300 ppm GA_3), T13 (6 g l^{-1} yeast + 0 ppm GA_3), T14 (6 g l^{-1} yeast + 100 ppm GA_3), T15 (6 g l^{-1} yeast + 200 ppm GA_3), and T16 (6 g l^{-1} yeast + 300 ppm GA_3). The experimental design was a completely randomized block with three replications for each treatment. Seeds of lemon balm were sown in a nursery on the 15th of November during the two seasons under plastic low-tunnels. The 15-20 cm seedlings were transplanted into the field in early April, 40 cm apart in rows 50 cm wide. The area of each plot was 4 m^2 with three rows contained a total of 15 plants. The plants were sprayed twice with GA_3: the first spray four weeks after transplanting to the field; the second in July, 2 weeks after the first harvest. The foliar application of yeast was applied to leaves two weeks after the GA_3 spraying.

The following data were recorded for the two harvests (July and October): plant height (cm), number of branches, fresh and dry weight of plant (g/plant or kg/ha), EO yield per plant, and EO constituents.

Growth, yield, and chemical composition during the two seasons were statistically analyzed according to the procedure of Snedecor and Cochran (1980). The means of the treatments were compared using the least significant difference test at the 0.05 level. Hundred gram fresh weight of *M. officinalis* leaves were subjected to hydrodistillation using the method of Guenther (1961) and analyzed by GC-MS. The identification of volatile oil chromatogram's peaks was by comparing their mass spectra and retention times with those of standard *Melissa* EO, library and Adams (1989). The isolated EO was dehydrated over anhydrous sodium sulphate and stored in a refrigerator until gas chromatography (GC) analysis. The gas chromatograph (Perkin Elmer Model 3920B) was equipped with a thermal conductivity detector and a 2 m × 3 mm column packed with 10% Carbowax 20Mon 80/100 Chromsorb WAW, and hydrogen was used as the carrier gas at 0.5 $cm^3\ s^{-1}$. Temperature of injector, column and detector was 200, 130 and 200°C, respectively.

RESULTS AND DISCUSSION

Spraying lemon balm plants with different concentrations of GA_3 amended with 6 g l^{-1} yeast increased plant height, number of branches, plant fresh and dry weight, and EO percentage compared with the control sprayed with water (**Table 3**). The largest values of growth and EO yield occurred with T16 (6 g l^{-1} yeast + 300 ppm GA_3), but the lowest values of growth and EO yield were observed in the control. The same trends were observed in the second season, but with slight differences in values as shown in **Table 4**. The stimulating effect of GA_3 on plant height is due to its effect on cell elongation. A similar effect of GA_3 on enhancing plant height was obtained by Foury (1977) on globe artichoke (*Cynara scolymus* L.). In addition, the enhancing effect of yeast on growth and EO yield of lemon balm plants may be due to its high content of minerals, in particular N, P and K, and also the high content of vitamin B, which plays an important role in improving plant growth

Table 4 Effect of GA_3 and dry yeast on growth, yield and essential oil percentage of lemon balm during the second season.

Treatments	Gibberellic acid (GA_3 in ppm)	Plant height (cm)		No. of branches		Plant fresh weight (g)		Plant dry weight (g)		Plant dry weight ha^{-1} (t)		Essential oil (% dry weight)	
		I*	II**	I*	II**	I*	II**	I*	II**	I*	II**	I*	II**
Yeast	0	42.60	34.10	6	10	542.40	381.20	135.60	92.98	3.88	2.67	0.41	0.19
0 g l^{-1}	100	48.00	42.00	7	12	561.53	513.77	136.96	125.31	3.90	3.57	0.46	0.23
	200	58.30	48.30	11	15	658.70	605.30	166.76	147.63	4.76	4.21	0.44	0.26
	300	65.40	54.30	12	16	698.30	671.04	174.58	169.88	4.97	4.86	0.47	0.32
Mean value of yeast 0 g l^{-1}		53.58	44.68	9.00	13.25	615.23	542.83	153.48	133.95	4.38	3.83	0.45	0.25
Yeast	0	47.00	36.00	9	12	531.47	442.00	132.87	107.80	3.78	3.07	0.49	0.29
2 g l^{-1}	100	50.60	46.00	10	17	615.30	532.10	150.07	129.78	4.28	3.71	0.53	0.31
	200	59.30	56.60	12	16	686.19	619.78	173.72	154.95	4.95	4.43	0.53	0.33
	300	63.20	58.00	14	18	703.66	633.76	175.92	160.45	5.02	4.59	0.49	0.33
Mean value of yeast 2 g l^{-1}		55.03	49.15	11.25	15.75	634.16	556.91	158.15	138.25	4.51	3.95	0.51	0.32
Yeast	0	51.00	48.00	9	13	614.10	543.00	153.53	132.44	4.38	3.78	0.51	0.34
4 g l^{-1}	100	62.30	50.00	10	17	690.85	605.80	168.50	147.76	4.81	4.21	0.50	0.37
	200	66.30	62.30	12	20	760.75	700.20	192.59	170.78	5.50	4.88	0.52	0.35
	300	68.40	65.87	13	17	750.30	718.00	187.58	181.77	5.36	5.19	0.47	0.33
Mean value of yeast 4 g l^{-1}		62.00	56.54	11.00	16.75	704.00	641.75	175.55	158.19	5.01	4.52	0.50	0.35
Yeast	0	58.60	52.30	12	19	695.10	636.09	173.78	155.14	4.97	4.43	0.52	0.35
6 g l^{-1}	100	64.50	58.00	12	19	726.40	662.90	177.17	161.68	5.07	4.62	0.54	0.37
	200	70.00	66.00	17	22	802.00	747.93	203.04	182.42	5.81	5.21	0.50	0.34
	300	72.00	69.00	14	22	800.30	757.50	200.08	191.77	5.71	5.47	0.48	0.34
Mean value of yeast 6 g l^{-1}		66.28	61.33	13.75	20.50	755.95	701.11	188.52	172.75	5.39	4.93	0.51	0.35
Mean value of GA_3 at: 0		49.80	42.60	9.00	13.50	595.77	500.57	148.945	122.09	4.25	3.49	0.48	0.29
100		56.35	49.00	9.75	16.25	648.52	578.64	158.18	141.13	4.52	4.03	0.51	0.32
200		63.48	58.30	13.00	18.25	726.91	668.30	184.03	163.95	5.26	4.68	0.50	0.32
300		67.25	61.79	13.25	18.25	738.14	695.08	184.54	175.97	5.27	5.03	0.48	0.33
LSD (5%)	GA_3	1.77	1.85	0.9	1.1	10.6	12.3	8.2	9.1	0.29	0.33	0.04	0.05
	Yeast	2.36	2.47	0.7	0.8	9.80	11.24	7.1	6.4	0.21	0.14	0.02	0.02
	GA_3 x Yeast	3.58	3.94	1.0	1.4	19.25	21.45	12.3	13.58	0.43	0.40	0.03	0.08

*I – first harvest, **II – second harvest

Table 5 Chemical composition of lemon balm essential oil as affected by yeast and/or GA_3 treatments.

Compounds	Relative concentration of compounds (%)							
	Control	T4	T13	T16	Control	T4	T13	T16
	Harvest 1				Harvest 2			
Camphene	0.13	0.12	0.13	0.10	0.13	0.13	0.14	0.09
β-pinene	0.09	0.07	0.08	0.04	0.09	0.12	0.04	0.23
β-phellandrene	0.05	0.06	0.03	0.05	0.06	0.07	0.10	0.09
Limonen	0.74	0.88	0.81	0.63	0.32	1.14	1.12	0.85
α-terpinene	0.40	0.64	0.44	0.64	0.42	0.24	0.34	0.63
cymene	0.82	1.14	1.12	1.23	1.16	0.85	1.20	0.95
6-methyl-5-heptene-2-ol	3.82	3.88	4.12	4.16	3.24	5.16	5.23	6.17
linalool	0.82	1.14	1.01	0.93	0.65	0.93	0.84	1.32
citronellal	13.35	16.38	14.26	16.21	11.26	13.65	14.65	10.21
β-caryophyllene	4.85	4.63	4.31	5.81	5.65	7.16	5.84	8.35
neral	18.74	17.45	12.10	18.21	26.34	28.33	22.14	15.64
geranial	26.84	28.17	30.18	32.12	24.15	17.60	26.13	29.16
geranyl acetate	1.65	0.87	0.97	1.15	1.99	0.73	0.84	0.94
neryl acetate	1.42	2.10	1.82	1.82	1.76	0.94	0.82	0.75
geraniol	4.23	1.86	4.34	2.99	6.14	2.10	4.16	4.21
nerol	0.64	0.75	1.65	0.13	0.35	0.21	0.42	0.14
β-caryophyllene oxide	9.94	7.43	8.12	4.13	6.30	5.17	7.35	8.16
Total of identified compounds	88.51	87.57	85.50	90.36	90.02	84.53	91.37	87.91
Total of unidentified compounds (unknowns)	11.49	12.43	14.51	9.64	9.98	15.47	8.63	12.09
Total	100	100	100	100	100	100	100	100

Control - 0 g l^{-1} yeast + 0 ppm GA_3, sprayed with water, T4 - 0 g l^{-1} yeast + 300 ppm GA_3, T13 - 6 g l^{-1} yeast + 0 ppm GA_3, T16 - 6 g l^{-1} yeast + 300 ppm GA_3

(Subba 1984). Furthermore, vitamin B affects meristemic tissue, plant growth and development indirectly by stimulating the endogenous levels of different plant hormones such as cytokinins and gibberellins (Kodendaramaiah and Gopala Rao 1985).

These results are in agreement with those of El-Khateeb (1989) and Mohamed and Wahba (1993) for rosemary (*Rosmarinus officinalis*), Turky (1989) for coriander (*Coriandrum sativum*), Shedeed *et al.* (1990) and Bedour *et al.* (1995) for basil (*Ocimum basilicum*), and Abou-Taleb *et al.* (1998) for thyme (*Thymus vulgaris*), all of whom reported that foliar spray of GA_3 resulted in the highest values of vegetative growth including plant height and fresh and dry weight of the investigated plants, using GA_3 at a range of 50-400 ppm. Mousa (1994) found that GA_3 at 200 ppm increased the plant height, and fresh and dry weight, but that GA_3 treatments (50, 100, 150 or 200 ppm) had no significant effect on the number of branches/plant; however, they significantly increased the total number and fresh and dry weight of the flowering heads of marigold (*Calendula officinalis*) and rue (*Ruta graveolens*) plants.

The highest EO percentage (0.32 and 0.37%) was obtained by spraying the yeast at 6 g l^{-1} while the lowest EO percentage (0.17 and 0.19%) resulted with the control treatment (0 g l^{-1} yeast + 0 ppm GA_3), as shown in **Tables 3** and **4**. All treatments altered the composition of EO in lemon balm plants. These results agree with those of Liang *et al.* (1996), who studied the effect of foliar application of GA_3

on chemical composition of leaves of the tea plant (*Camellia sinensis*). They found that the concentration of amino acids increased by 9.8% while the concentration of polyphenols and the polyphenol: amino acids ratio decreased by 9.9 and 11.5%, respectively. The response to gibberellins differed between clones and with shoot development stage. Weathers *et al.* (1996) found that the addition of GA_3 (0.001-0.01 mg^{-1}) to *Artemisia annua* increased the biomass yield. Artemisinin production was best with GA_3 (0.01 mg^{-1}).

Values in **Table 5** are of lemon balm EO analysis of the first season only; values of the second season showed a similar trend with slight differences in values. The analysis of the EO in lemon balm (**Table 5**) showed the presence of 17 compounds. The major compound was geranial, followed by neral. The minor compounds were α-pinene and β-phellandrene. Fresh weight of 100 g of *M. officinalis* leaves of different treatments were subjected to hydrodistillation and analyzed by GC-MS. The identification of the peaks in the volatile oil's chromatogram was through the comparison of their mass spectra with those of standard *Melissa* EO, library and Adams (1989), listed in **Table 5**. Total identified compounds percentage were 88.513, 87.57, 85.495, 90.361, 90.02, 84.53, 91.37 and 87.91 for control, T4 (0 g l^{-1} yeast + 300 ppm GA_3), T13 (6 g l^{-1} yeast + 0 ppm GA_3) and T16 (6 g l^{-1} yeast + 300 ppm GA_3) for the first and second harvests, respectively.

The major amount of volatile principle was oxygenated compounds which constituted 81.45, 80.03, 78.57, 81.85, 82.18, 74.82, 82.58 and 76.71% of total volatile constituents for control, T4, T13 and T16 for the first and second harvests, respectively. The major oxygenated compound is geranial (26.84% for control group) followed by neral (18.74%), citronellal (13.35%), β-caryophyllene oxide (9.94%), geraniol (4.23%) and 6-methoxy-5-heptene-2-ol (3.82%).

The oxygenated compounds constituted oxide form as β-caryophyllene oxide (9.94, 7.433, 8.120, 4.130, 6.300, 5.170, 7.350 and 8.160% for control, T4, T13 and T16, for the first and second harvests, respectively, all treatments decreased the β-caryophyllene oxide percentage compared to the control group. The percentage alcohol was 9.51, 7.63, 11.12, 8.21, 10.38, 8.4, 10.65 and 11.84% for control, T4, T13 and T16, for the first and second harvests, respectively, the GA_3 treatment decreased the percentage alcohol (7.63 and 8.4%; first and second harvests, respectively), which was increased by the application of yeast in the first and second harvests (11.12 and 10.65%) as compared to control group. The percentage aldehydes was 58.93, 62, 56.54, 66.54, 61.75 59.58, 62.92 and 55.01% for control, T4, T13 and T16, for the first and second harvests, respectively; all treatments increased the aldehyde percentage compared to the control group, GA_3 being the most effective. The acetate derivatives were 3.07, 2.97, 2.79, 2.97, 3.75, 1.67, 1.66 and 1.69% for control, T4, T13 and T16 for the first and second harvests, respectively. Values of the first harvest show that, the major alcohol was geraniol (4.23%) followed by heptene-2-ol (3.82%), while aldehydes were the main compounds of lemon balm volatile oil (58.93%). The aldehyde compounds are composed of geranial (26.84% for control group), neral (18.74%) and citronellal (13.35%). The acetate derivatives are geranyl acetate (1.65%) and neryl acetate (1.42%) while the only oxide compound detected was β-caryophyllene oxide (9.94%). In conclusion GA_3 foliar application is superior to all other treatments to increase the percentage of oxygenated compounds, especially aldehyde compounds, while the application of yeast is the best treatment to increase the percentage alcohol.

The amount of volatile hydrocarbons are 7.07, 7.54, 6.92, 8.51, 7.84, 9.71, 8.78 and 11.2% for control, T4, T13 and T16 for the first and second harvests, respectively. The major hydrocarbons are β-caryophyllene (4.85%) followed by cymene (0.82%) then limonene (0.74%). The hydrocarbon percentage was increased by application of yeast while it decreased by application of GA_3.

CONCLUSION

Using 6 g l^{-1} active dry yeast + 300 ppm GA_3 resulted in the best lemon balm plant growth and yield.

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